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## HYDROLOGICAL RESPONSES OF RIVER BASINS TO LAND USE CHANGE IN SUSTAINABLE BUILT ENVIRONMENTS

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### ABSTRACT

Changes in land use, particularly the conversion of forests and agricultural land into urban settlements, alter hydrological responses by increasing runoff, raising peak discharge, and reducing baseflow. These changes affect flood risk, environmental quality, and the sustainability of built environments in rapidly urbanizing tropical regions.

**Aims:** This study aims to systematically review applications of Soil and Water Assessment Tool (SWAT) and SWAT+ models to analyze hydrological responses to land use changes and evaluate their implications for urban flooding and sustainable built environments.

**Methodology and results:** A Systematic Literature Review was conducted using Scopus-indexed and nationally accredited Indonesian journals. Studies were selected using keywords related to land use change, hydrological response, river basins, and SWAT or SWAT+ modelling. The results show that urbanization increases runoff, peak discharge, and sediment yield, while vegetation enhances infiltration and hydrological stability. Common parameters include streamflow, runoff, baseflow, and sediment yield. Performance is evaluated using NSE, R<sup>2</sup>, and PBIAS.

**Conclusion, significance and impact of the study:** This review confirms that SWAT and SWAT+ support spatial planning and sustainable watershed management. It highlights the importance of integrating of hydrological modeling into land use planning to improve flood resilience and identifies gaps in future flood risk scenarios.

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- Urban flooding

## 1. INTRODUCTION

Hydrological studies play a vital role in water resource management, especially in river basins where land use is rapidly changing due to urban development. Hydrology examines the movement, distribution, and quality of water, as well as its interaction with human activities. This provides a fundamental basis for understanding river flow dynamics, infiltration processes, and surface–groundwater interactions [1][2][3][4][5][6]. Rapid population growth and the increasing land demand for agriculture, settlements, and industry have made land use change a major driver of hydrological alteration, especially in tropical regions undergoing accelerated urbanization.

Land use changes directly influence river flow characteristics and flood behavior [7]. The conversion of forested areas into agricultural or residential land generally increases surface runoff and reduces soil infiltration [10], resulting in higher flow volumes and velocities that elevate flood risk in settlement areas. These changes also degrade water quality through increased sediment loads and pollutant concentrations associated with human activities [8]. In addition, the combined effects of land use change and climate variability exacerbate hydrological extremes and flood risk in vulnerable regions [9][10]. Studies in the Cisadane River Basin in Indonesia report that converting forest to agriculture has increased river discharge by up to 30%, significantly intensifying flood potential during the rainy season [11][12]. These findings underscore the importance of systematically assessing hydrological responses to support sustainable spatial planning [13].

Hydrological modeling is essential for analyzing the impacts of land use changes. The SWAT and SWAT+ models are widely used because they can simulate land use scenarios and quantify hydrological responses such as runoff, baseflow, sediment yield, and flooding potential [14][15]. However, existing studies are fragmented by regions and contexts, which limits a comprehensive understanding. This study addresses this gap by conducting a systematic literature review (SLR) to synthesize current evidence, identify research trends and modelling practices, and pinpoint remaining gaps in SWAT/SWAT+ applications [16]. Based on these objectives, the study was designed to answer the following research questions:

RQ1: How have SWAT and SWAT+ models been applied to assess the hydrological responses to land use changes in river basins that support urban settlements and built environments?

RQ2: Which hydrological variables (e.g., streamflow, surface runoff, baseflow, sediment yield, and flooding indicators) are most frequently analyzed in SWAT/SWAT+-based studies?

RQ3: How do international and Indonesian studies differ in their application of SWAT/SWAT+ models to evaluate the impact of land use changes on hydrological responses?

RQ4: What input data, calibration, and validation methods are commonly used in SWAT/SWAT+ studies analyzing hydrological responses to land use change?

RQ5: What research gaps remain in applying SWAT/SWAT+ models to support sustainable watershed management and urban flood resilience in tropical regions such as Indonesia?

This study also provides strategic recommendations for sustainable water resource management in areas affected by land use change. It does so by identifying vulnerable zones and appropriate mitigation strategies through an SLR approach.

## 2. RESEARCH METHODOLOGY

This study uses a systematic literature review (SLR) to collect, analyze, and synthesize scientific literature relevant to land use change and hydrological responses [17]. This approach allows for the identification of research trends, methodological practices, and existing gaps across diverse geographical contexts. The journal selection was limited to Scopus-indexed publications that focus on applying the SWAT+ model to analyze the impact of land use changes on river flow, and that support their findings with clear methodologies and reliable results [18]. Relevant articles were identified using keyword combinations related to SWAT, flooding, and land use. Then, the abstracts and conclusions were screened. The selected studies were analyzed in depth to extract the modeling approaches, simulation results, and study locations [19]. The findings were synthesized by grouping land use types, hydrological impacts, and modeling methods, which allowed for the identification of common patterns and key differences across studies [20][21][22][23].

### 2.1 Systematic Approach to Literature Review

This study uses the SWAT+ model [24] to conduct a systematic evaluation of existing literature on the hydrological responses of river basins to land use change. The applied review framework ensures a structured synthesis of previous studies while enabling critical assessment of recent advances in hydrology and watershed management relevant to build environments [25][26]. This approach involves formulating clearly defined research questions to examine key issues, identify emerging research directions, and evaluate the effectiveness of SWAT+ applications in analyzing the impact of land use change on river flow dynamics [27][28][29]. This structured synthesis enhances the validity and relevance of the findings, allowing the results to contribute both to

scientific knowledge and practical applications of sustainable water resource management in tropical regions [30][31][32].

## **2.2 Data Collection Process**

Data were collected through a systematic literature search using three primary sources: the Scopus database, Google Scholar, and Indonesian journals accredited by Sinta 1 and Sinta 2. These sources were selected to ensure comprehensive coverage of high-quality international studies and research relevant to the Indonesian context [33]. Scopus provided peer-reviewed articles with globally recognized standards [34], while Google Scholar broadened the search to include context-specific studies on tropical watersheds [35]. Sinta 1 and Sinta 2 journals were included to strengthen national-scale perspectives on water resource management.

Scopus searches used the keywords ‘SWAT model’ OR ‘Soil and Water Assessment Tool’ AND ‘flood’ OR ‘flood risk’ OR ‘flood modelling AND ‘land use’ OR ‘land cover’ to identify global studies on hydrological responses to land use change. Google Scholar searches used more specific terms related to hydrological responses, flooding, and Indonesian watersheds. Additional literature was obtained through targeted searches of Sinta-accredited journals. These were then manually screened based on titles and abstracts to ensure relevance to hydrological responses in tropical river basins.

## **2.3 Selection of Inclusion and Exclusion Criteria**

To ensure the quality and relevance of the reviewed literature, clearly defined inclusion and exclusion criteria were applied [36][37]. Included studies were peer-reviewed articles published between 2010 and 2025 that analysed hydrological responses to land use change using the SWAT or SWAT+ models. These studies had clearly described methodologies and documented hydrological assessments [38]. Studies were excluded if they were not peer-reviewed, were irrelevant to the research objectives, did not apply SWAT or SWAT+, or were published outside the defined period. Conference abstracts, non-scientific reports, and studies with incomplete data or unclear methods were also excluded. The article selection process was systematic. It began with keyword-based searches across selected databases, followed by title and abstract screening. Relevant studies were then subjected to a full-text review to extract key information on hydrological responses and SWAT/SWAT+ applications.

## 2.4 Data Analysis

To ensure relevance to the research objectives, the authors conducted a systematic and in-depth literature analysis. Data were collected from multiple sources and selected based on clearly defined criteria. The selection process was documented with a PRISMA flow diagram illustrating the identification, screening, and final inclusion of studies. The diagram is shown below:

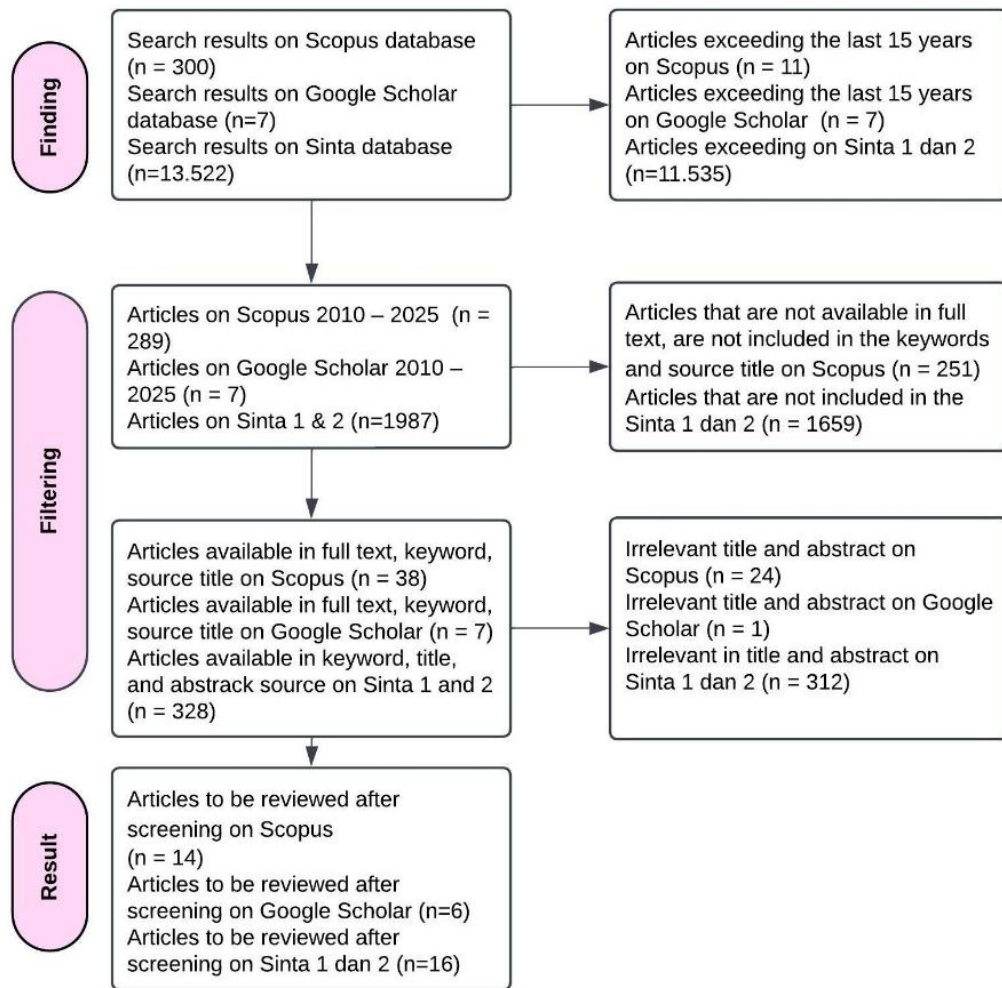


Fig. 1 Prism Diagram

## 3. RESULTS AND DISCUSSION

Table 1 presents a summary of the key findings on using of the SWAT+ model to evaluate hydrological responses to changes in land use. The synthesis highlights modeling approaches, input data, and simulation results related to changes in river discharge, runoff, baseflow, and

sedimentation. It provides valuable insights into flood risk assessment and sustainable watershed management.

**Table 1.** Comprehensive Summary of SWAT-Based and Related Hydrological Studies

| Paper Title   | Model               | Hydrological Factors                       | Research Results   | Calibration & Validation               | Research Gap                                   |
|---|---------------------|--|--|--|--|
| Impacts of LULC changes on runoff (Zhanghe River Basin, China), 2024  | SWAT + LU-SVM + SVM | Runoff                                     | Model combinations improve accuracy ( $R^2$ 0.89–0.90); urbanisation increases runoff; forests reduce peak discharge | $R^2$ between simulation & observation | Not yet tested in other watersheds / long-term |
| Adaptation of SWAT for Stormwater Management (Austin, Texas), 2025  | SWAT                | Runoff, flooding, water quality            | Effective assessing LULC & stormwater management   | Validation in 5 watersheds             | Not optimal for complex drainage systems       |
| Impacts of Land Use & Climate Changes on Flood (Upper Wei River, China), 2025   | SWAT                | Land use/land cover, rainfall, temperature | Barren land $\uparrow$ runoff 90%; forests reduce peak discharge   | $R^2$ & NSE 0.75–0.78                  | Extreme & socio-economic scenarios not tested  |
| Streamflow changes due to climate & LULC (Philippines), 2023  | SWAT                | Rainfall, ET, runoff                       | Rainfall $\downarrow$ 18.6% (dry); runoff $\uparrow$ 27.9% (rainy)   | Calibration of runoff & flow           | No agricultural adaptation tests & uncertainty |
| Application of SWAT model with CMADS data to estimate hydrological elements and parameter uncertainty based on SUFI-2 algorithm in the Lijiang River basin, China, 2018 | SWAT + SUFI-2       | Parameter uncertainty                      | NSE > 0.8; SUFI-2 effective for sensitivity  | SUFI-2 & CMADS data                    | Long-term LULC impacts not discussed           |
| Simulation of land use scenarios in the Camboriú river basin using the SWAT model, 2017   | SWAT                | Urbanisation, forests, agriculture         | Urbanisation $\uparrow$ runoff; forests reduce peak discharge  | -                                      | No climate analysis yet                        |
| The hydrological response to human activities in Guishui River basin, Beijing, 2025   | SWAT                | Human activity                             | Urbanisation $\uparrow$ runoff, $\downarrow$ baseflow  | -                                      | No future projections                          |
| Coupling SWAT+ and SWMM Models to Quantify Streamflow in  | SWAT + SWMM         | Runoff, drainage flow                      | Combined models improve accuracy   | NSE & $R^2$ increased                  | Water/sediment quality not assessed            |

## Hydrological Responses of River Basins to Land Use Change in Sustainable Built Environments

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| Paper Title   | Model                                 | Hydrological Factors                     | Research Results                                       | Calibration & Validation     | Research Gap                            |
|---|---------------------------------------|--|--|------------------------------|---|
| Mixed Rural–Urban Watersheds, 2025  |                                       |  |  |                              |   |
| Run-off modelling of pervious and impervious areas using couple SWAT and a novel machine learning model in cross-rivers state Nigeria, 2023   | SWAT + ML                             | Surface runoff                           | $R^2 > 0.85$ ; better peak discharge prediction        | -                            | Not validated across regions            |
| Application of swat model with cmads data for hydrological simulation in western China, 2020  | SWAT                                  | Meteorological data                      | NSE 0.74; $R^2$ 0.78; accurate in minimal data regions | CMADS calibration            | No LULC analysis yet                    |
| Modelling hydrological response to land use/cover change: case study of Chirah Watershed (Soan River), Pakistan, 2020   | SWAT                                  | Runoff, groundwater recharge             | Runoff $\uparrow$ 24%; recharge $\downarrow$ 8%        | NSE 0.63; RVE $< \pm 5\%$    | Climate not considered                  |
| Evaluating SWAT model performance, considering different soils data input, to quantify actual and future runoff susceptibility in a highly urbanized basin, 2020  | SWAT                                  | Soil, rain, runoff                       | Low resolution soil data performed best                | Validation of 3 soil configs | Future LULC integration not implemented |
| Assimilation of Sentinel 1 and SMAP – based satellite soil moisture retrievals into SWAT hydrological model: the impact of satellite revisit time and product spatial resolution on flood simulations in small basins, 2020 | SWAT + EnKF                           | Soil moisture, flooding                  | Daily discharge accuracy improved                      | Daily discharge validation   | No LULC analysis yet                    |
| Runoff potential estimation of Anjana Khadi Watershed using SWAT model in the part of lower Tapi Basin, West India, 2016  | SWAT                                  | Runoff, flooding                         | High urbanisation $\rightarrow$ maximum runoff         | PUAR validation              | No LULC scenario yet                    |
| Watershed Management Approach As An Alternative Solution For Flood Problem In Northern Part Of Central Java, 2022   | Socio-ecological watershed management | Environmental & social watershed quality | No socio-hydrological comparison                       | Survey & field observation   | Social aspects not integrated into SWAT |

| Paper Title   | Model                          | Hydrological Factors       | Research Results                  | Calibration & Validation                       | Research Gap                             |
|---|--------------------------------|----------------------------|-----------------------------------|--|--|
| Identification of Flood-Prone Sub-Watersheds using the Cendana Method (Case Study: Aesesa Watershed in the Flores River Region), 2023                             | Spatial & topographic analysis | Peak discharge, flood risk | Not compared with SWAT            | DEM, rainfall, land cover                      | Need SWAT for dynamic flood prediction   |
| Flood Inundation Modelling for the Lower Bengkulu Sub-Watershed of Bengkulu Province Using the Hec-Ras 5.0.7 Program Based on Ras Mapper and Arc-Gis 10.8, 2023   | HEC-RAS                        | Flood modelling            | Overseas often combined with SWAT | DEM, rainfall, topography                      | No rainfall-runoff integration with SWAT |
| Parameter Determination of the NRECA Model for Discharge in the Temef Watershed, 2022   | NRECA Model                    | Flow rate                  | Local focus only                  | Rainfall & climate data                        | Cross-validation with SWAT required      |
| Analysis of Available Discharge in the Temef Watershed Using the NRECA, F. J. Mock and Tangki Method, 2021  | Simple models (non-SWAT)       | Discharge & availability   | SWAT abroad more accurate         | Rainfall & evapotranspiration                  | Further SWAT study required              |
| Impact Of Land Cover Change And Replacement From Seasonal To Annual Crops On Surface Runoff And Sediment Yield In The Upstream Cimanuk Watershed, Indonesia, 2023 | SWAT                           | Runoff, erosion            | In line with global results       | DEM, rainfall, land cover; NSE, R <sup>2</sup> | Improve rainfall & land data resolution  |
| Application of Rainfall – Runoff Model for Assessing the Effect of Land Use Change on Flood Characteristic in Serang Regency, Banten, 2022                        | SWAT input analysis            | Topography & delineation   | External studies use high-res DEM | SRTM vs ASTER comparison                       | DEM limitation in Indonesia              |
| A novel remote sensing-based calibration and validation method for distributed hydrological modelling in ungauged basins, 2025                                    | SWAT + RS                      | Runoff, ET, baseflow       | Accurate flow estimation          | Satellite & SWAT-CUP                           | No hydrological LULC response testing    |
| Implementation of the Zero Runoff System (ZROS) and the   | Conservation approach          | Runoff & infiltration      | In line with overseas studies     | Rainfall, slope, land                          | Not fully integrated into SWAT           |

| Paper Title   | Model                       | Hydrological Factors         | Research Results                    | Calibration & Validation                 | Research Gap                         |
|---|-----------------------------|------------------------------|-------------------------------------|--|--------------------------------------|
| Effectiveness of Reducing Surface Runoff on Sloping Land in the Cidanau Watershed, Banten, 2017   | ch (SWAT inputs)            |                              |                                     |  |                                      |
| The Impact of Land Cover Changes on Flood Hydrograph Characteristics (Jragung dam Case Study), 2023   | SWAT                        | Peak discharge, hydrograph   | Consistent globally                 | DEM, rainfall; NSE validation            | Limited land & daily rainfall data   |
| Evaluation of the Sustainability Status of Land Use in the Upper Ciliwung River Basin, 2020   | SWAT                        | Erosion, sediment, discharge | Equivalent to international studies | DEM, soil, rainfall, land cover          | Needs economic-spatial integration   |
| Study of Sedimentation Control on Bangga River, Palu Watershed, Central Sulawesi, 2023  | SWAT                        | Sediment & river flow        | In line with overseas research      | DEM, soil, rainfall                      | Limited long-term data               |
| River Morphological Study of Downstream Paneki River in Palu Watershed Following The Earthquake and Liquefaction Disaster at Central Sulawesi, 2023 | Post-disaster morphology    | River shape changes          | Overseas integrates SWAT            | River & satellite data                   | Need SWAT-morphology integration     |
| Assesment of morphometric and hydrological properties of small watersheds in East Java Regions, 2019  | Morphometric analysis       | Runoff potential             | External studies use SWAT           | DEM, rainfall, topography                | Requires SWAT validation             |
| Application of SWAT Model for Assessing Water Availability in Surma River Basin, 2019   | SWAT                        | Runoff, ET                   | Consistent internationally          | DEM, soil, rainfall; NSE, R <sup>2</sup> | Spatial data limited                 |
| Optimization of Embung Jinggring for Water Resources Development of the Sadar Watershed, Mojokerto, East Java, 2019                                 | Water resource optimization | Discharge & storage          | No external comparison              | Local hydro-topographic data             | Need SWAT integration in design      |
| Dynamic Eco-Drainage System Modelling in Wetland Areas (Case Study of the Kelapa Gading Area, DKI Jakarta), 2022                                    | LID approach                | Runoff & infiltration        | In line globally                    | Field test data                          | Not linked with SWAT urban modelling |
| Soil Water Analysis Tools (SWAT) hydrology modelling as a basis for   | SWAT                        | Runoff, baseflow, sediment   | Runoff ↑; baseflow ↓; worse         | R <sup>2</sup> 0.62; NSE 0.51            | Climate variability                  |

| Paper Title  | Model           | Hydrological Factors          | Research Results                  | Calibration & Validation     | Research Gap                              |
|--|-----------------|-------------------------------|-----------------------------------|------------------------------|---|
| spatial planning: a case study in Cimandiri Watershed, West Java Province, 2017  |                 |                               | planning scenarios                |                              | not discussed                             |
| Analysis of Climate Change Impacts on Agricultural Water Availability in Cimanuk Watershed, Indonesia, 2022              | SWAT            | Rainfall, temperature, runoff | Runoff ↑; baseflow ↓; Qmax/Qmin ↑ | Daily discharge validation   | Social aspects & adaptation not discussed |
| The Impact of Land-Use and Climate Change on Water and Sediment Yields in Batanghari Watershed, Sumatra, Indonesia, 2023 | SWAT + SWAT-CUP | Runoff & sediment             | Increased runoff & sediment       | Automatic calibration 'good' | Land conservation not discussed           |
| Spatial Analysis of Water Infiltration Potential in the Miu Watershed of Sigi Regency, 2023                              | GIS             | Land, rain, slope             | 82% area well drained             | GIS validation               | SWAT not yet applied                      |
| Flood Prone Area Analysis in the Wonosari Sub Watershed, Bondowoso Regency, East Java, 2025                              | SWAT            | Runoff, slope, land           | Flood-prone mapping               | Debit & topography data      | Limited local data & land scenarios       |

### 3.1 The SWAT/SWAT+ Model in assessing Hydrological Responses to Land Use Change in Various Watersheds

Numerous studies demonstrate the effectiveness of SWAT and SWAT+ in analysing hydrological responses to land use/land cover changes and climate variability, particularly with regard to urban flooding. Urbanization increases surface runoff, peak discharge, and flood risk, while forest cover enhances infiltration and reduces peak flows. These models are widely used to simulate streamflow, groundwater recharge, sediment yield, and flood dynamics to support spatial planning and flood mitigation efforts. Integrating these models with machine learning and urban models (e.g. SWAT–BiLSTM, SWAT–SWMM) improves performance and achieves runoff prediction accuracy up to  $R^2 \approx 0.90$ . In Indonesia, SWAT-based studies have reported increased runoff and sediment yield, and reduced baseflow due to urbanization and deforestation. Using satellite data and automatic calibration enhances performance; however, accuracy remains highly dependent on data quality and urban representation.

### 3.2 Hydrological Factor Analysis

The hydrological variables most analyzed using SWAT/SWAT+ include streamflow, surface runoff,

baseflow, lateral flow, and sediment yield. Additional focus is given to evapotranspiration, infiltration, soil erosion, and extreme flooding. Discharge and surface runoff are the focus of many analyses due to their sensitivity to land use changes and their importance in urban flood risk assessments. Studies in the Jatigede, Jragung, Upper Cijung, and Bangga watersheds have shown that land conversion increases peak discharge, runoff, and sediment yield, while conservation scenarios reduce these impacts. Indonesian studies primarily emphasize streamflow, baseflow, and sediment yield, reflecting flood and erosion vulnerability in tropical basins. In contrast, international research adopts a broader scope, integrating the effects of climate variability and urbanization on extreme flows. Model performance is commonly evaluated using SWAT-CUP, SUFI-2, and statistical indicators such as  $R^2$ , NSE, PBIAS, and RVE. These evaluations confirm the reliability of SWAT/SWAT+ for flood-oriented watershed planning.

### 3.3 Comparison of International and Indonesian Studies

International studies typically use sophisticated modelling techniques and combine data from multiple sources, including remote sensing, satellite imagery, and automated calibration tools such as SWAT-CUP and SUFI-2. These studies analyse the interactions between urbanization, land use changes, and climate variability in long-term and extreme scenarios. The results show that urban expansion increases runoff and peak discharge, while forest conversion reduces baseflow. Additionally, climate change intensifies hydrological variability and urban flood risk. Model performance is typically evaluated using statistical indicators such as  $R^2$ , NSE, and PBIAS, alongside spatial validation. In contrast, Indonesian studies primarily focus on applied, site-specific analyses to support spatial planning and watershed management in tropical basins. Despite their more limited analytical scope, their findings are consistent with international results, indicating increased runoff, reduced baseflow, and higher flood risk due to land conversion. Integrating advanced modeling techniques would improve prediction accuracy and flood risk management in Indonesia.

### 3.4 Calibration and Validation Methods

Calibration and validation are critical methodological components in SWAT/SWAT+–based hydrological studies. These methods ensure a reliable assessment of the impacts of land use changes. Calibration optimizes sensitive parameters to improve simulations of streamflow, surface runoff, baseflow, and sediment yield. Automatic tools such as SWAT-CUP and SUFI-2 are widely used for the purpose. These tools improve the models' ability to capture the hydrological

responses to forest conversion, agricultural expansion, and urban development. Several Indonesian case studies, including the Jatigede and Surma watersheds, report satisfactory calibration results, as indicated by high NSE and  $R^2$  values. Validation evaluates predictive accuracy using statistical indicators such as  $R^2$ , NSE, PBIAS, and RVE, supported by comparisons with observed discharge data. Spatial validation using GIS-based flood-prone mapping further strengthens confidence in SWAT/SWAT+ applications for analysing peak flows, baseflow dynamics, and urban flood risk.

### 3.5 Research Gaps in SWAT/SWAT+ Modelling for Urban Flood Risk in Tropical Watersheds

Although research on tropical watersheds has advanced our understanding of the hydrological responses to land use and climate change, significant gaps remain, particularly with regard to urban flooding. While most studies focus on the direct impact on discharge, runoff, and sediment, the combined long-term effects of climate variability, rapid urbanization, and spatial development on urban flood dynamics remain poorly examined. The limited integration of socio-economic factors, land use policies, and human adaptation further limits the usefulness of model outputs for adaptive flood management. Data limitations persist, as many studies rely on low-resolution spatial data and short hydrometeorological records, which increases uncertainty. Although remote sensing products and automatic calibration tools are being used more frequently, integrating field data and conducting cross-regional validation remains limited. Methodologically, the dominance of single deterministic models underscores the necessity of integrated frameworks that combine SWAT+, machine learning, and socio-economic components to bolster urban flood resilience in tropical regions.

## 4. CONCLUSION

This systematic literature review confirms that SWAT and SWAT+ models are widely used to analyse hydrological responses to land use and climate change in tropical watersheds. These models effectively simulate streamflow, runoff, baseflow, and sediment yield, thereby supporting spatial planning and urban flood assessment. Studies from both Indonesia and other countries show that urbanization increases runoff and peak discharge, thereby elevating flood risk, while conservation reduces these impacts. However, limitations remain, including low data resolution, limited spatial validation, and weak integration of socio-economic and policy factors. International studies tend to apply more advanced approaches, whereas Indonesian research is largely site-specific. Future research should emphasize integrated, adaptive modeling

frameworks to strengthen sustainable watershed management and urban flood resilience.

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